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EFFECTS OF TEMPERATURE AND MIXER SPEED ROTATION ON RHEOLOGICAL PROPERTIES OF SPREADS WITH MALTITOL

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ABSTRACT

Sucrose-free spreads containing different share of maltitol (100, 70 and 30% as a bulking agents) are investigated with the aim to improve energy. Spreads with maltitol were produced in ball mill. The quality of produced spread mass is determined by moisture, size of the largest cocoa particle, yield stress and Casson plastic viscosity. The lowest energy values have spreads containing 100% maltitol. Spreads with maltitol do not have hygroscopic nature (moisture parameters are constant). Regardless of the sweetener type, spreads produced at maximum mixer speed rotation (50 r/min) have the lowest size of largest particle. Spreads containing 100% maltitol have greater plastic viscosity and significant viscous properties. Dynamic oscillatory measurements showed the spreads with different maltitol share are the viscoelastic solids, with dominate elastic component. The viscous component is dominant at lower frequencies (frequency <2 Hz). According to the rheology parameters, the best and the worst solution is if sucrose is replaced with maltitol, as a bulking agent, 100 and 30%, respectively.

PRACTICAL APPLICATION

Sugar-free confectionary products have become very popular nowadays. The energy value of spreads could be improved by selection of appropriate sweetener (maltitol). Hence, the maltitol share in this study would benefit the reducing energy value of spreads. It would be also useful for the future research to find the optimal maltitol share in spreads under different process conditions. The results confirm that rheology properties of spreadable food play important role in consumers' acceptability, because they indicate the moment that system starts to flow.

INTRODUCTION

Spreads are confectionery products based on sugar, vegetable fat, cocoa powder, milk powder and other ingredients with good spread ability in wide temperature range (from ambient to fridge temperature), rich creamy taste and homogeneous smooth structure, without oil phase migration. The confectionery industry participates in development and popularization of low-energy food; where of the traditional sugar (sucrose) is replaced by another sweetener, such as maltitol. Consuming the confectionery products with reduced energy values, consumers are satisfying their needs for sweet taste, maintaining or decreasing their body weight, without consequences to own health (Bobroff 2005; Petković *et al.* 2012). Maltitol is white crystalline sugar alcohol (polyol), with the sweetness degree from 0.75 to 0.90 and energy value 10 kJ (2.4 kcal) (Fritz 2006; Nelson 2009). The maximum daily recommended intake of maltitol depends on consumer organism condition, its age, sex, etc., and is 50 g total. Negative characteristic of maltitol is a direct result of its over consummation, manifesting as windiness and gaseous (Sokmen and Gunes 2006). According to Konar (2013), maltitol is suitable fine sugar substitute in milk chocolates.

Rheological properties of spreads are formed by mixing, grinding (under the influence of mill balls) and mass recirculation within the ball mill, where the surface of each particle being wrapped by fat phase (Servais *et al.* 2004; Petković *et al.* 2012). The viscosity of chocolate and cocoa cream mass (spreads), above the process parameters (temperature, mixer speed rotation), is affected by (Vavreck 2004; Schantz and Rohm 2005) fat phase content (Timms 2003; Beckett 2008), solids content (Chevalley 1999; Sokmen and Gunes 2006), water content (Beckett 2008) and type/amount of present surfactants (Chevalley 1999; Rector 2000; Timms 2003; Afoakwa *et al.* 2007). The International Confectionery Association (ICA) suggested the use of rotational viscometer with concentric cylinders (bob and cup) and the Casson equation in a shear rate range of 5–60/s (OICCC 1973; ICA 2000; Servais *et al.* 2004; Sokmen and Gunes 2006). Viscoelastic properties of spreads are explained using the modulus (elastic modulus G′ and viscous modulus G″) (Mezger 2002). Yield stress notably decreases with the use of maltitol (Konar 2013).

Size of largest cocoa particle has a direct influence of rheological and sensory properties. The largest particles are more important to sensory properties (mouthfeel grittiness) and the small particles influence of rheological properties (flow properties) (Beckett 2003, 2008). Chocolate with particle size above 35 mm becomes gritty or coarse in the mouth resulting in lower acceptability (Servais *et al.* 2004; Sokmen and Gunes 2006)

The aim of this work was to test the possibility of complete or partly sucrose replacement with maltitol in spread production, by a nonconventional producing method (using the ball mill), and the influence of process parameters (temperature, mixer speed rotation) on rheological properties of spreads.

MATERIAL AND METHODS

Material

Ingredients of analyzed spreads are sucrose (Crvenka AD, Serbia), maltitol (C* Maltidex CH 16385, Cargill, Germany), palm fats (Loders Croklaan, Pasir, Gudang, Malaysia), cocoa powder (Bary Calebaut, Zurich, Switzerland), soy flour (Soy protein AD, Becej, Serbia), whole milk powder (Polsera, Poland), lecithin (Soy protein AD, Serbia) and flavor (nature identical aroma of vanilla and hazelnut, Curt Georgi, Germany).

Preparation of Spread Samples

Formulation of spreads (Table 1) used total fat content over 32%; since above fat content of 32% there are a few changes in yield value with any further additions (Afoakwa *et al.* 2008). Spreads were produced by a nonconventional producing method (using the ball mill).

Experiment Plan

Four groups of spread samples were analyzed. The first group of samples represents the spreads with sucrose (S samples), the other, a combination 70% sucrose and 30% maltitol (SM samples), the third group consists of spread samples obtained by 70% maltitol and 30% sucrose (MS samples) and fourth with 100% maltitol (M samples). Spreads for each group were produced at different temperatures (30C, 35C, 40C) and mixer speed rotation (30, 40, 50 r/min). For instance, a sample of spread with 100% sucrose, produced at a temperature of 35C and mixer speed rotation 50 r/min, will be marked as S–35–50. The other spreads were marked analogically (sweetener–temperature–mixer speed rotation). Spreads were produced in a laboratory ball mill. Raw materials were measured and added into the homogenizer at once, where they were blended for 30 min at adequate temperature. The diameter of balls in the mill was 9.1 mm and the grinding period of spread mass is 150 min. Experimental samples (50 g) were closed by thermo weld in a white plastic glaces and stored at 25C.

Chemical Analyses

The basic chemical composition of spread mass was determined using standard AOAC methods (AOAC 2000) (Table 2).

Size of the Largest Cocoa Particles

The size of the biggest cocoa particles was determined by the microscopic method (the greatest linear dimensions of the cocoa particles).

Determination of Rheological Characteristics

Rheological measurements were analyzed on a rotational viscometer Haake Rheo Stress 600 (Thermo electron

TABLE 1. RECIPE FOR THE SPREAD FORMULATION

Ingredient	Sweetener	Palm fat	Cocoa powder	Whole milk powder	Soy flour	Lecithin	Flavor
(%)	47.4	36	7	7	2	0.5	0.1

TABLE 2. THE BASIC CHEMICAL COMPOSITION OF SPREADS

Quality factor	Method/principle	S	M	SM	MS
Moisture (%)	Thermogravimetric	1.06	0.78	0.73	0.75
Total fat (% d.m.)	Soxhlet	39.27	39.22	39.11	39.19
Total proteins (% d.m.)	Kjeldahl	4.78	4.66	4.81	4.75
Total carbohydrates (% d.m.)	Polarimetric	51.92	5.94	37.64	16.63
Cocoa components (% d.m.)	Spectrophotometric	7.40	7.50	7.43	7.44
Nonfat cocoa components (% d.m.)	Spectrophotometric	6.50	6.42	6.43	6.51
Sucrose (% d.m.)	Polarimetric	47.91	1.18	33.32	14.28
Lactose (% d.m.)	Iodine metric titration	1.83	1.77	1.80	1.82
Energy value (kcal)	Calculation	2,428.80	2,036.91	2,327.60	2,141.70
Energy value (kJ)	Calculation	581.05	487.30	556.84	512.36

[Karlsruhe] Gmbh, Germany). Measurements were analyzed 40 ± 0.1C, in the range of shear rate of 0–60/s (Casson model, International Office of Cocoa and Chocolate, Bruxelles, Belgium) (ICA 2000; Pajin 2009). The tests use concentric cylinder system (sensor Z20 DIN, Thermo electron [Karlsruhe] Gmbh). The shear rate was increased from 1 1/s to 60 1/s within 240 s, and was then kept constant at a maximum speed of 60 1/s for 60 s. At the end, the shear rate was reduced to 1 1/s within 240 s.

Statistical Analysis

The software package Statistica 8.0 (Graphics Software System) was used to check the proportion values of viscous and elastic modules (at 95% significance level, $P \le 0.05$). Regression analysis of experimental value is mathematically defined as the influence of independent variables (x – temperature, y – mixer speed rotation) on dependent variable (z – proportion values of viscous and elastic modules-phase shift, loss-coefficient $\tan\delta = G''/G'$). Highly responsive function z is defined by the regression equation (mathematical model) the following forms

$$z = b_0 + b_1x + b_2y + b_{11}x^2 + b_{12}xy + b_{22}y^2 \qquad (1)$$

where b_0, b_1, b_2, b_{11}, b_{12}, b_{22} are regression coefficients. The regression coefficients b_1 and b_2 show a linear effect of independent variables x and y on the dependent variable z, b_{11} and b_{22} quadratic effect, where b_{12} indicates the linear interaction of independent variables (Radocaj *et al.* 2011).

RESULTS

Chemical Analyses

Data from the basic chemical analyses (Table 2) shown variation in energy and moisture values.

Size of the Largest Cocoa Particles

The maximum and minimum size of largest cocoa particles are shown in Table 3.

Determination of Rheological Characteristics

Flow Curves. Flow curves were produced by standard procedure and graphically shown in Fig. 1.

Influence of temperature and mixer speed rotation on yield stress, viscosity and thixotropic area are shown in Table 4. Casson yield values for dark chocolates have been reported to be between 4 and 32 Pa (Aeschlimann and Beckett 2000).

Dynamic Oscillatory Measurements. The dynamic oscillatory measurements are graphically shown (Figs. 2, 3, 4 and 5).

Statistical Analysis

The obtained experimental results were statistically analyzed to study the correlation between process parameters (temperature, mixer speed rotation) and loss-coefficient ($\tan\delta$, Table 5) shown in Table 6.

DISCUSSION

Chemical Analyses

Energy values of spreads (Table 2) were decreased by growing the maltitol proportion (the energy value of

TABLE 3. THE MAXIMUM (D_{MAX}) AND MINIMUM (D_{MIN}) SIZE OF LARGEST COCOA PARTICLES FOR SPREADS

Spread type	D_{max}	D_{min}
S	88.55 μm (S–30–30)	73.12 μm (S–35–50)
M	70.58 μm (M–35–30)	61.67 μm (M–35–50)
SM	72.43 μm (SM–35–40)	69.16 μm (SM–40–40)
MS	64.50 μm (MS–35–50)	62.76 μm (MS–40–50)

μm; micrometer; S–30–30, type of sweetener (S, sucrose; M, maltitol)–temperature (C)–mixer speed rotation (r/min).

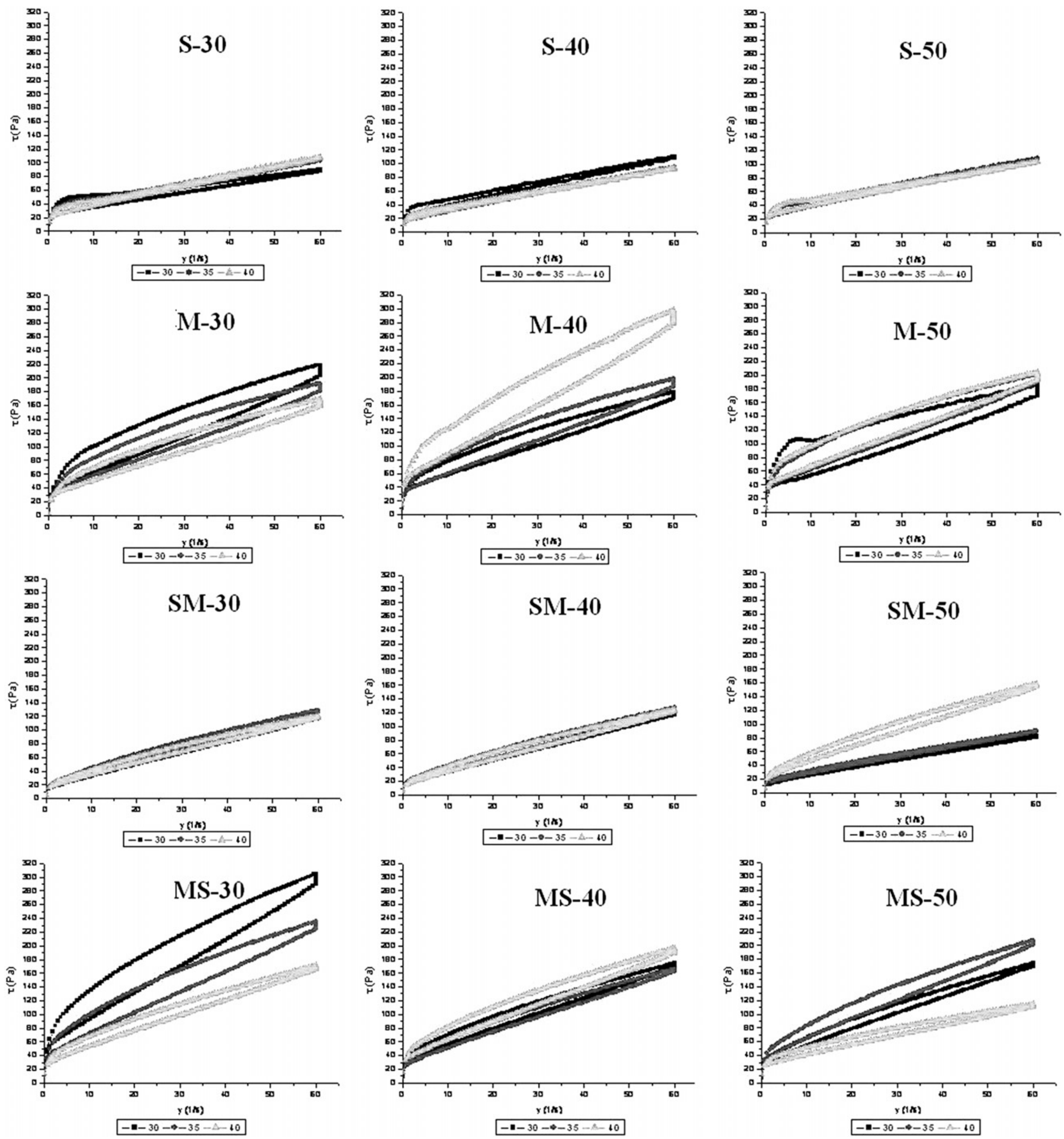

FIG. 1. THE FLOW CURVES OF SPREADS AS A FUNCTION OF MIXER SPEED ROTATION PRODUCED AT 30C, 35C AND 40C

maltitol is 40% lower than sucrose). The lowest energy value has spread produced with 100% maltitol. The spreads with 100% sucrose (S) have highest values of moisture (1.06%), as a consequence of significant hygroscopic nature of sucrose.

Size of the Largest Cocoa Particles

The largest particles are important for mouthfeel with respect to grittiness. Particles larger than 30 μm cause a gritty perception (Beckett 1994; Afoakwa *et al.* 2008).

TABLE 4. INFLUENCE OF TEMPERATURE AND MIXER SPEED ROTATION ON YIELD STRESS, VISCOSITY AND THIXOTROPIC AREA

Spread	t_0 (Pa)	η (Pas)	P (Pa/s)	Spread	t_0 (Pa)	η (Pas)	P (Pa/s)
S–30–30	7.380	0.912	575.8	M–30–30	5.562	7.137	2,099
S–30–40	8.560	1.806	447.7	M–30–40	7.847	4.717	1,181
S–30–50	8.532	1.216	374.0	M–30–50	9.486	4.061	2,436
S–35–30	7.571	1.216	401.9	M–35–30	3.286	5.583	1,547
S–35–40	6.340	1.597	220.0	M–35–40	8.132	6.030	1,469
S–35–50	8.716	1.728	401.3	M–35–50	6.397	5.748	1,715
S–40–30	8.249	1.794	364.6	M–40–30	2.958	4.490	1,177
S–40–40	7.291	1.430	241.0	M–40–40	11.680	13.636	2,342
S–40–50	9.324	1.506	361.8	M–40–50	5.527	5.672	1,613
Average	7.999	1.466	376.45		6.764	6.342	1,731.0
SM–30–30	2.758	2.730	479.4	MS–30–30	11.680	14.094	2,229.0
SM–30–40	4.080	2.680	542.1	MS–30–40	7.174	4.907	837.9
SM–30–50	4.070	1.218	263.4	MS–30–50	6.182	5.166	643.1
SM–35–30	3.464	3.099	499.0	MS–35–30	9.149	8.614	1,570.0
SM–35–40	6.415	3.018	497.0	MS–35–40	5.994	4.730	682.2
SM–35–50	2.868	1.425	233.2	MS–35–50	9.028	7.004	1,049.0
SM–40–30	4.080	2.693	451.7	MS–40–30	8.179	4.795	818.8
SM–40–40	6.134	3.001	481.7	MS–40–40	12.930	6.015	999.5
SM–40–50	5.562	4.493	669.3	MS–40–50	8.086	1.821	549.2
Average	4.381	2.706	457.42		8.711	6.349	1,042.1

t_0 (Pa)–yield stress; η (Pas)–Casson plastic viscosity; P (Pa/s)–thixotropic area.
S–30–30, type of sweetener (S, sucrose; M, maltitol)–temperature (C)–mixer speed rotation (r/min).

Increasing temperature and mixer speed rotation, the size of largest cocoa particles become smaller, such the blending process is more efficient (Table 3). Spreads produced at maximum mixer speed rotation (50 r/min), regardless of temperature and sweetener type, have the lowest largest particle size. The highest values of particles have spreads with dominant sucrose content (S–30–30 [88.55 μm] and SM–35–40 [72.43 μm]), representing the hygroscopic effect of sucrose and its partially recrystallization (forming the agglomerates).

Determination of Rheological Characteristics

Flow Curves. The smaller particles are important with respect to chocolate flow properties in particular to the yield stress (Beckett 1994). All analyzed spreads (Fig. 1) are classified as pseudoplastic solid, with pronounced thixotropic loop. The S spreads have stable system. Increasing the mixer speed rotation is expressed as a dominance of elastic properties; this effect is particularly pronounced at higher temperatures (35 and 40C) and maximum mixer speed rotation (50 r/min).

The viscosity of M spreads is higher than the viscosity of S spreads, at the same process parameters. Yield value is affected largely by interparticle contacts and specific surface area (Seguine 1988). More pronounced values of thixotropic area of M spreads indicate the existence of highly inhomogeneous structure, representing the consequence of presence too small and coarse maltitol crystals, which are the reasons of unfavorable incorporation of solid particles in fat phase. The temperature parameter is dominant; lower temperature parameters give the dominant elastic properties and increasing the temperature parameter results unfavorable incorporation of particles and inhomogeneous structure. Increasing the temperature parameter (35C and 40C), at maximum mixer speed rotation (40 and 50 r/min), viscous properties of SM spreads are dominant. The thixotropic area of SM spreads are somewhat higher than the area of spreads made with sucrose (S spreads), indicating the disturbed structure. The addition of maltitol results the system has become inhomogeneous, but it is far less than the inhomogeneity of the spreads with maltitol (M spreads). Values of thixotropic area of MS spreads show a strong inhomogeneity of the system, which is the result of increasing the maltitol share in ingredient content. However, this system is more homogeneous than spreads with 100% maltitol as a sweetener. Increasing the mixer speed rotation, the solid particles are more divided (greater compactness of the system) and the structure is homogeneous (the thixotropic areas are decreased).

Casson plastic viscosity values for chocolate is between 2.1 and 3.9 Pas (Aeschlimann and Beckett 2000). Viscosity of spreads with maltitol in our study is in this range and larger than with sucrose. Casson yield values (6.764, 4.381, 8.711 Pa for M, SM and MS spreads, respectively) fell in

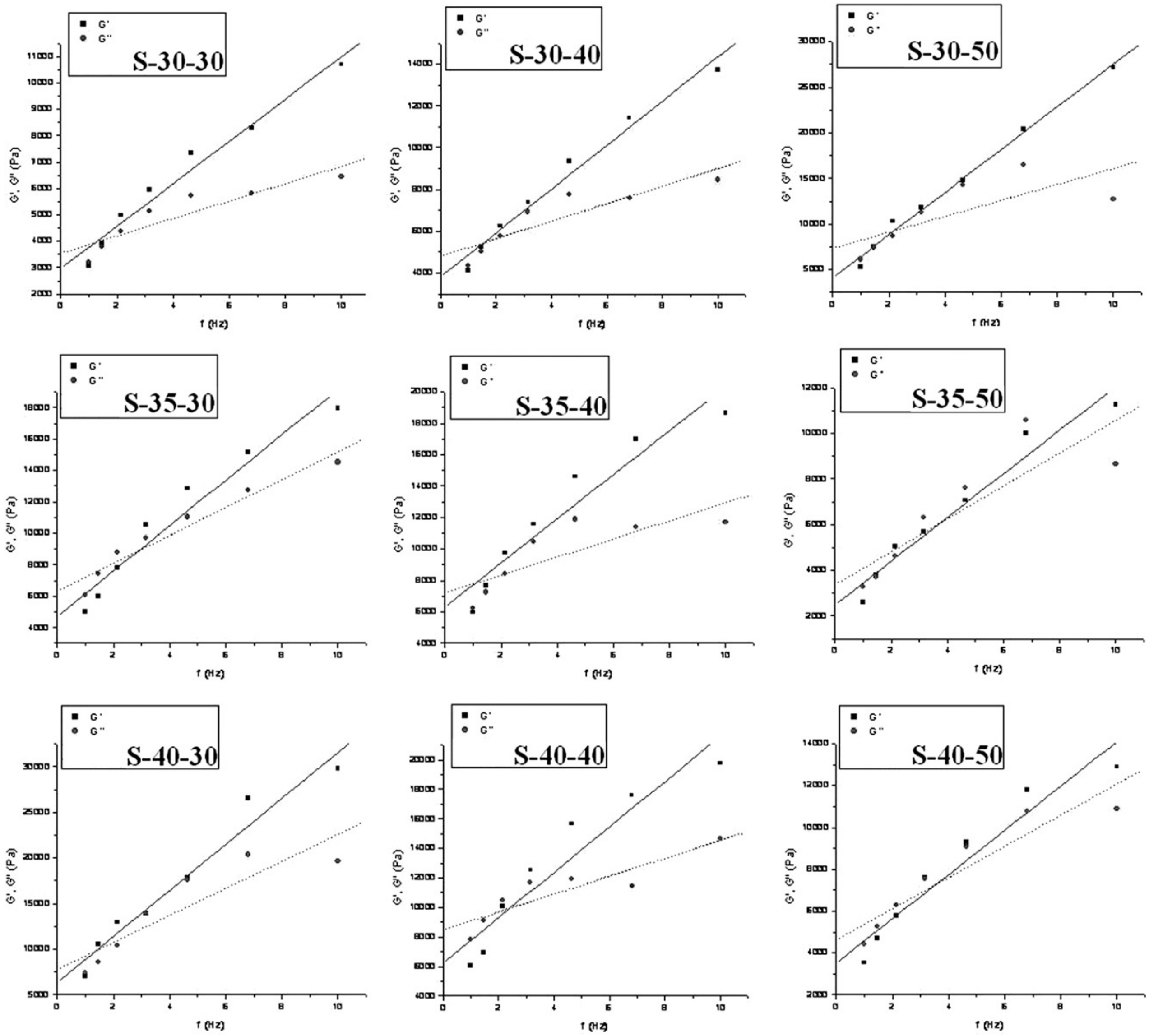

FIG. 2. THE ELASTIC AND VISCOUS MODULES OF SPREADS WITH SUCROSE AS A FUNCTION OF FREQUENCY AND PROCESS PARAMETERS (TEMPERATURE AND MIXER SPEED ROTATION)

range of yield values for chocolate too (Aeschlimann and Beckett 2000).

Influence of sweetener type (sucrose, maltitol, combination of sucrose and maltitol) is more expressed, than the process parameters (Table 4). Addition of maltitol causes the decrease of yield stress, growing viscosity and thixotropic area of spreads with maltitol as a sweetener. Higher plastic viscosity of spreads with maltitol may be associated with its slightly lower density (1.60 g/cm^3) than sucrose (1.63 g/cm^3) (Sokmen and Gunes 2006). Increasing the temperature, yield stress and viscosity of S spread grow up and the thixotropic area becomes lower. The temperature dominance is expressed on M spreads too; increasing the temperature, yield stress, viscosity and thixotropic area become lower. The maximum values of these parameters are at 40C. Higher plastic viscosity in low-fat product can be explained as when distribution of particle sizes becomes wider with a large specific surface area, the smaller particles fill spaces between larger, reducing viscosity of suspensions for any given solid concentration (Servais *et al.* 2002). The sweetener combination in SM and MS spreads causes a huge variation in rheology results, so there was no possibility to define the influence of process parameters.

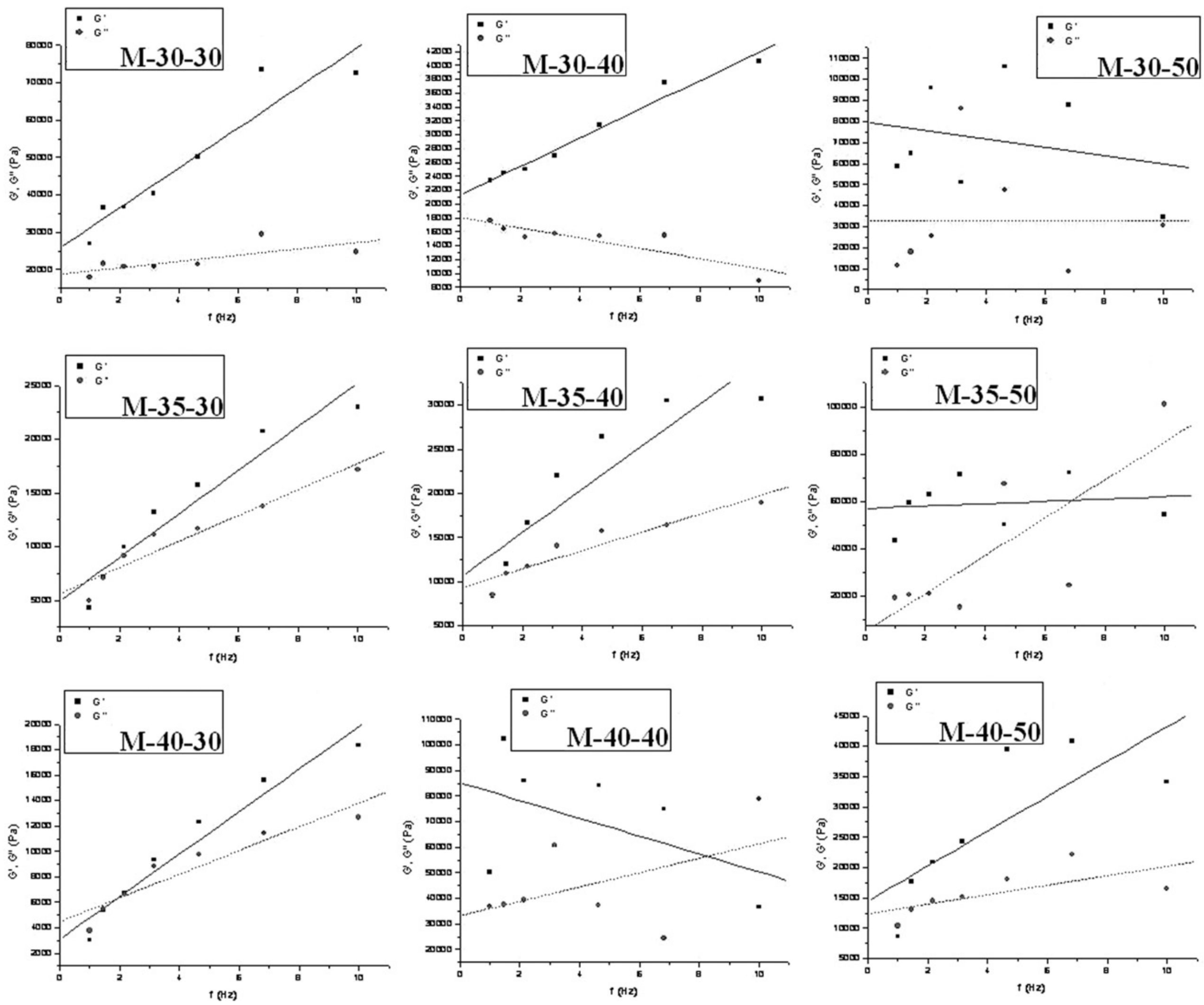

FIG. 3. THE ELASTIC AND VISCOUS MODULES OF SPREADS WITH MALTITOL AS A FUNCTION OF FREQUENCY AND PROCESS PARAMETERS (TEMPERATURE AND MIXER SPEED ROTATION)

Dynamic Oscillatory Measurements. Beckett (1994) and Afoakwa *et al.* (2007) have noted that chocolates of high viscosity have a persisting pasty mouthfeel and that this viscosity is related to particle size, composition and process strategy. The results of dynamic oscillatory measurements of S spreads (Fig. 2) are alike concentrated solutions, with a point of intersection (crossover point) between the line of elastic modulus and the line of viscous modulus (Steffe 1996). Point of intersection occurs at equality of these modulus ($G' = G''$, $\delta = \pi/4$). Increasing the process parameters, the point of intersection moves to higher frequencies, where the dominance of viscous properties stops over elastic properties. The maximum value of $\tan\delta$ has spread produced at 40C and 50 r/min.

Due to unfavorable incorporation of particles and extremely inhomogeneous structure, the results of modules of M spreads are completely undefined and unclear (Fig. 3).

Analyzing the SM spreads (Fig. 4), the dominant elastic properties of viscoelastic systems were noticed for spreads produced at lowest mixer speed rotation (SM–30–30), while the spread produced at maximum mixer parameter (50 r/min) has dominant viscous component. The spread produced at 30C and mixer speed rotation 40 r/min shows the characteristics of concentrated solutions, with expressive point of intersection. In this system, the elastic component is dominant, according to system behavior where sucrose is more present.

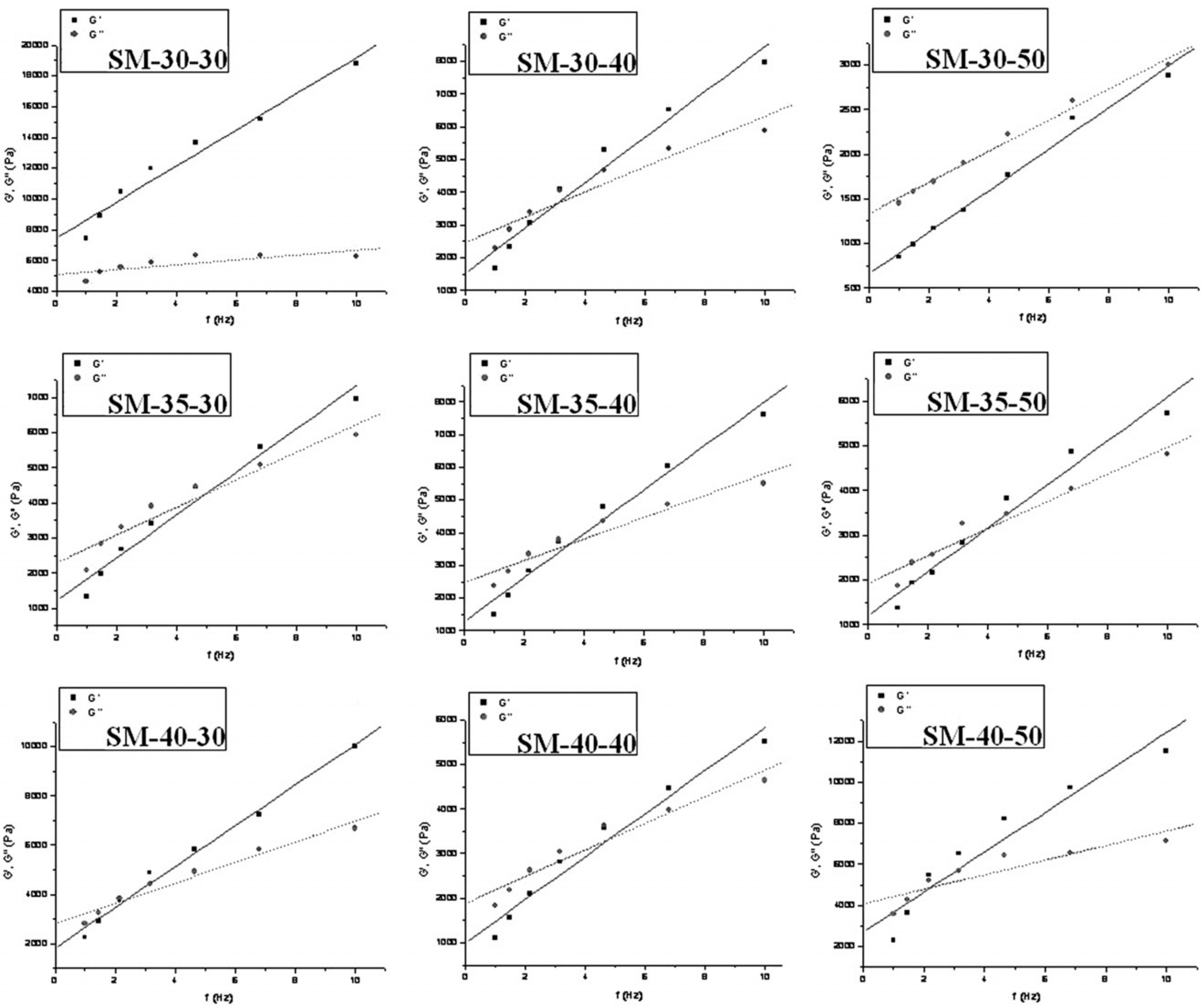

FIG. 4. THE ELASTIC AND VISCOUS MODULES OF SPREADS WITH 70% SUCROSE AND 30% MALTITOL AS A FUNCTION OF FREQUENCY AND PROCESS PARAMETERS (TEMPERATURE AND MIXER SPEED ROTATION)

Point of intersection is identified to MS spreads (Fig. 5), produced at highest process parameters (40, 50 r/min, 40C), with the exception for spreads obtained at the minimum speed (30 r/min) and temperature parameter (30C, 35C). The elastic modules of spreads MS–30–30 and MS–35–30 are higher than viscous modules and the contribution of elastic component is greater (the elastic properties are dominant).

All analyzed spreads are viscoelastic systems, with dominant elastic component (the measured values of elastic modules are higher than the values of viscous modules). This characteristic is very important in process design and quality assessment for materials such as butter or spreads (Steffe 1996). For spreads with a point of intersection, the viscous component is dominant at lower frequencies (frequency <2 Hz), where the viscous modules are greater than elastic modules, up to point of intersection, where the elastic component becomes more dominant in system. After the point of intersection, spreads show a clear tendency for more solid-like behavior (at higher frequencies).

Statistical Analysis

Analyzing the experimental results (Table 6) with sucrose (S spreads), the temperature is more dominant parameter (the highest values of linear reg. coeff. b_1); increasing the mixer speed rotation the elastic properties become dominant. This effect is particularly pronounced at higher temperatures (35 and 40C) and maximum mixer speed rotation (50 r/min). Statistical analyses for spreads with maltitol (M spreads)

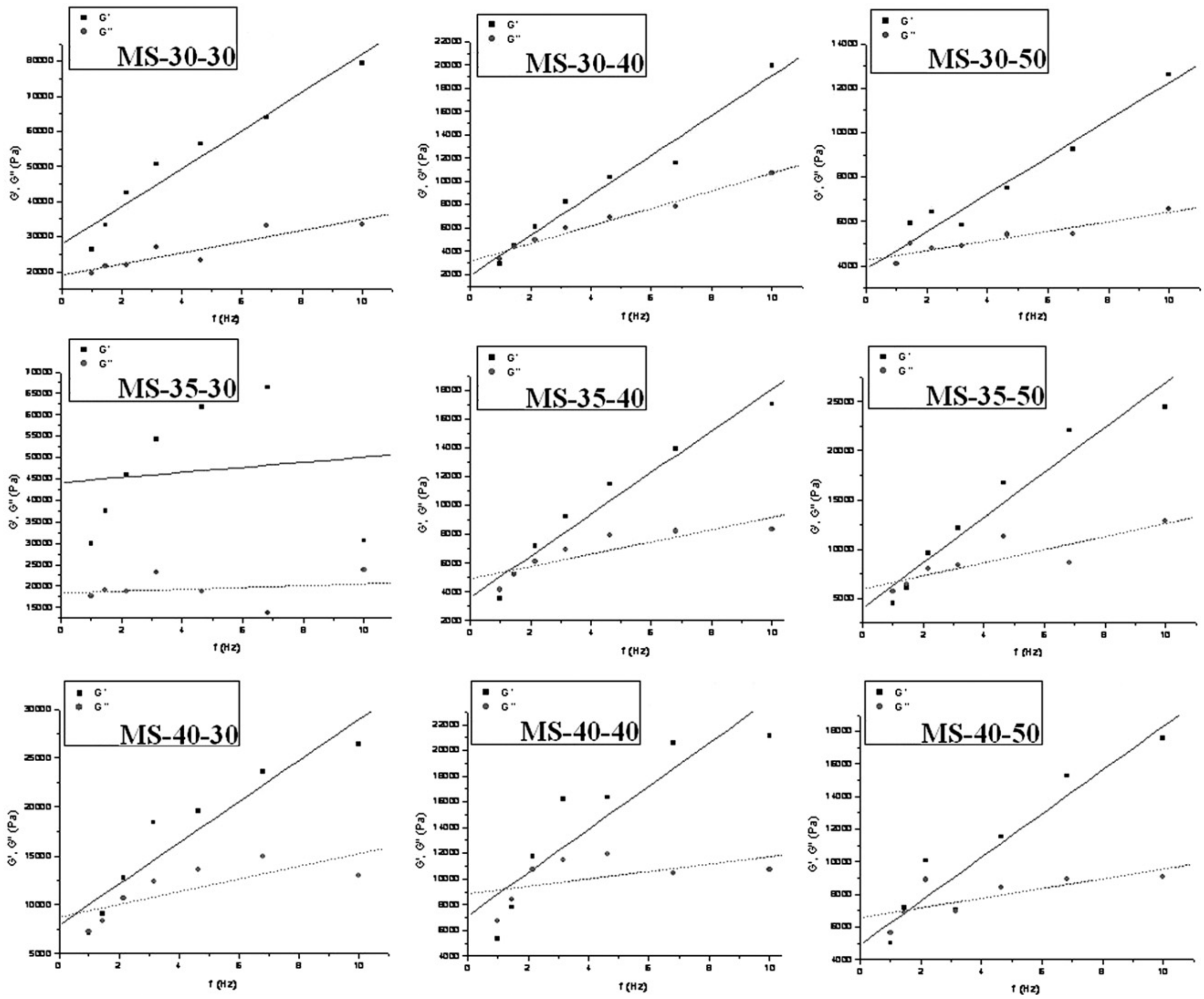

FIG. 5. THE ELASTIC AND VISCOUS MODULES OF SPREADS WITH 70% MALTITOL AND 30% SUCROSE AS A FUNCTION OF FREQUENCY AND PROCESS PARAMETERS (TEMPERATURE AND MIXER SPEED ROTATION)

TABLE 5. INFLUENCE OF TEMPERATURE AND MIXER SPEED ROTATION ON PROPORTION OF VISCOUS AND ELASTIC MODULUS

tanδ							
Spread	tanδ	Spread	tanδ	Spread	tanδ	Spread	tanδ
S–30–30	0.8339	M–30–30	0.4923	SM–30–30	0.4992	MS–30–30	0.5406
S–30–40	0.8556	M–30–40	1.0192	SM–30–40	0.5332	MS–30–40	0.7869
S–30–50	0.8840	M–30–50	1.3595	SM–30–50	0.5514	MS–30–50	0.7508
S–35–30	1.0027	M–35–30	1.1621	SM–35–30	0.8656	MS–35–30	0.4600
S–35–40	0.8370	M–35–40	1.0790	SM–35–40	0.7950	MS–35–40	0.7935
S–35–50	1.0230	M–35–50	1.0723	SM–35–50	0.6974	MS–35–50	0.7781
S–40–30	0.8707	M–40–30	0.9421	SM–40–30	0.9162	MS–40–30	0.7540
S–40–40	0.9615	M–40–40	1.1646	SM–40–40	0.7813	MS–40–40	0.8142
S–40–50	1.0276	M–40–50	0.9499	SM–40–50	0.6783	MS–40–50	0.8270

tanδ = G″/G′.

S–30–30, type of sweetener (S, sucrose; M, maltitol)–temperature (C)–mixer speed rotation (r/min).

TABLE 6. CORRELATION BETWEEN THE PROCESS PARAMETERS (TEMPERATURE AND MIXER SPEED ROTATION) AND LOSS–COEFFICIENT (TANΔ) OF PRODUCED SPREADS

Regression coefficient (tanδ)	Spread			
	S	M	SM	MS
b_0	–0.317111	–8.13759	–12.7607	0.562341
b_1	0.124523	0.43740	0.5044	–0.153476
b_2	–0.059381	0.04631	0.2365	0.124542
b_{12}	0.000534	–0.00145	–0.0043	–0.000686
b_{11}	–0.001948	–0.00504	–0.0047	0.002735
b_{22}	0.000556	–0.00002	–0.0009	–0.001131
R^2	0.8813	0.9802	0.9279	0.8736

b_0, b_1, b_2, b_{11}, b_{12}, b_{22}, regression coefficients; R^2, coefficient of determination; S, M, SM, MS, sweetener type.

indicates the dominant temperature parameter (high values of linear regression coeffifient b_1 and $R^2 = 0.9802$); lower temperature parameters contribute to dominant elastic properties; increasing the temperature parameter values of tanδ vary as a result of the unfavorable incorporation of particles and inhomogeneous structure.

Both process parameters have a strong influence on viscoelastic proportion (linear regression coefficient b_1 and b_2) for SM spreads; increasing the temperature parameter (35 and 40C) at maximum mixer speed rotation (40 r/min and 50 r/min), viscous properties are dominant. The dominate process parameter, for MS spreads, is mixer speed rotation (the highest values of linear regression coefficient b_2); increasing the mixer speed rotation, at the same temperature, affects the changing values of tanδ to elastic limit.

The dominance of elastic properties of spreads containing maltitol (M, MS and SM) is extremely expressed for spreads produced at lowest process parameters (30C and 30 r/min). The elastic component has a higher value than twice as viscous.

The correlation coefficient values ($R^2 = 0.8736$–0.9802) show a very strong correlation between the obtained values of independent variables, making this model acceptable to predict the rheological behavior of spreads over temperature and mixer speed rotation changes.

CONCLUSION

Based on the results of testing the possibility of complete or partly sucrose replacement with maltitol in spread production and the influence of process parameters (temperature, mixer speed rotation) on rheological properties of spreads it can be concluded that:

Spreads produced at maximum mixer speed rotation (50 r/min) have the lowest share of the largest particles. As a result of sucrose hygroscopic feature and partially recrystallization, the largest particles have spreads with 100% sucrose and combination of 70% sucrose and 30% maltitol.

All spread samples are complex structural systems, classified as pseudoplastic solids, with pronounced thixotropic loop. Spreads with 100% maltitol have greater plastic viscosity and thixotropic area. The greatest plastic viscosity (13,636 Pas) and thixotropic area (2,342 Pa/s) has spread with 100% maltitol produced at 40C and 40 r/min. By increasing the temperature, yield stress and viscosity of spreads containing maltitol grow down and the thixotropic area becomes lower (the maximum values of these parameters have spreads produced at 40C). Yield values of maltitol spreads are affected by surface area of maltitol. Maltitol crystals, after grinding, are coarse and have inhomogeneous particle size distribution with a large specific surface area. Generally speaking, the combination of sweeteners (maltitols and sucrose) causes huge variations in rheology results. Spreads with 70% maltitol and 30% sucrose (MS spreads) show a huge rheology variation, regardless the process parameters. Rheology parameters point that the optimal and best solution is to replace all sucrose with maltitol (100% maltitol as a bulking agent). The worst solution is 30% sucrose replacement.

Because of unfavorable incorporation, spreads with maltitol do not have a point of intersection (crossover point) between the line of elastic modulus and the line of viscous modulus. Replacing the maltitol with sucrose, the point of intersection becomes visible. The elastic properties are dominant at lower mixer speed rotation (SM–30–30), while the spread produced at 50 r/min has dominant viscous properties. Point of intersection of MS spreads is identified at highest process parameters (40, 50 r/min, 40C). For spreads with a point of intersection, the viscous component is dominant at lower frequencies (frequency <2 Hz). After the point of intersection (frequency 2–10 Hz), spreads show a clear tendency for more solid-like behavior (at higher frequencies).

The results confirm that rheology properties of spreads play important role in consumer's acceptability, because they indicate the moment that system starts to flow.

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